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TITLE: DEVELOPMENT AND DEMONSTRATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS FOR REPROCESSING PLANTS

MASTER

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DEVELOPMENT AND DEMONSTRATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS FOR REPROCESSING PLANTS*

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ABSTRACT

A program to develop and demonstrate near-real-time accounting systems for reprocessing plants has been active at Los Alamos since 1976. The technology has been developed through modeling and simulation of process operation and measurement systems and evaluation of these data using decision analysis techniques. Aspects of near-real-time systems have been demonstrated successfully at the AGNS reprocessing plant as part of a joint study of near-real-time accounting.

I. INTRODUCTION

In 1976, the Los Alamos Safeguards Systems Group selected the Allied-General Nuclear Services Barnwell Nuclear Fuels Plant (AGNS BNFP) as the baseline facility for a series of studies to develop concepts for near-real-time accounting (NRTA) in reprocessing plants[1-7] to address national and international safeguards needs.

The advantages of NRTA systems are that they provide sensitive, timely, and localized detection of diversion or unexpected and unmeasured losses of nuclear material from the process area of a nuclear facility without disrupting normal operation of the facility. This is accomplished by collecting and analyzing data from existing or, in some cases upgraded, process instrumentation. In many respects, the objectives and techniques of NRTA parallel those of improved process control, making it attractive to plant operators. The advantages and the operational compatibility of NRTA are currently being demonstrated in a series of experiments at the AGNS BNFP.[8-11]

In this paper the Los Alamos effort to develop NRTA systems and to demonstrate in-plant NRTA systems is reviewed. The development of NRTA systems to meet national safeguards requirements, the extension of these systems to meet international safeguards requirements, and the demonstration of a NRTA system at the AGNS BNFP are described. Future directions and work to be accomplished in the continuing development of NRTA systems are discussed.

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II. DEVELOPMENT OF NRTA SYSTEMS FOR NATIONAL SAFEGUARDS

A. The Reference Plant MBA Structure

For these studies, the reference reprocessing plant is divided into four materials balance areas (MBAs): fuel receiving and storage, chop and leach area (MBA 1); chemical separations process area (MBA 2); uranyl-nitrate product storage area (MBA 3); and plutonium-nitrate product storage area (MBA 4). For better localization and control, these MBAs can be subdivided further into subMBAs, referred to as unit-process accounting areas (UPAAs). The chemical separations process area (MBA 2) can be treated as a single UPAA (referred to as UPAA 1 2), or it can be subdivided into two UPAAs: the codecontamination-partition process (UPAA 1) and the plutonium purification process (UPAA 2). These two UPAAs are shown in Figs. 1 and 2, respectively. The flow measurement separating these two UPAAs is on the 1BP stream, which is the first separated plutonium-nitrate stream in the standard Purex flow sheet.

1. UPAA 1 2--Chemical Separations Process.

The chemical separations process MBA is treated as a single UPAA (UPAA 1 2) by combining in-process inventory and flow measurements to form a dynamic materials balance ∿ every two days. On the average, under normal operating conditions, ∿2-1/2 accountability batches (∿5 tonnes of uranium fuel) and 1 product batch (∿50 kg of plutonium) are processed every day. Therefore, process logic suggests taking a materials balance ∿ every two days to include an integral number of feed and product batches. Smaller batches, for example to high-level waste, are included in the materials balances when the measurements become available. Alternatively, a materials balance could be taken around UPAA 1 2 after each feed batch (∿ every 9.6 h), if on-line flow and concentration measurements were added to the plutonium concentrator product stream.

2. UPAA 1--Codecontamination-Partitioning Processes. A separate UPAA (Fig. 1) could be formed around the codecontamination-partitioning processes if flow-rate and concentration measurements were added to the intermediate plutonium product (1BP stream). A dynamic materials balance can be formed for each feed accountability batch (every 9.6 h) by combining measurements of the concentration and volume of the feed batch, the concentrations and flow rates in the intermediate product, recycle, and waste streams, and the intervening in-process inventories in the process vessels.

3. UPAA 2--Plutonium Purification Process. Dynamic materials balances could be formed about the plutonium purification process (Fig. 2), if flow and concentration measurements were added to the aqueous and organic recycle streams. Process control measurements of the inventories in process tanks are available, and the inventories in the pulsed columns can be estimated by combining suitable engineering models with available process data on flow rates and concentrations of inlet and outlet streams.[12,13] One of two product measurements can be used: concentration and volume measurements in the plutonium product sample tank or integrated flow-rate and concentration measurements on the product stream of the plutonium product concentrator.

B. Materials Accounting Measurements in MBA 2

A variety of measurements are included in MBA 2 for conventional materials accounting. These measurements mostly consist of tank level and density, along with sampling and chemical analysis, to determine the residual holdup in the plant at the time of a shutdown, cleanout physical inventory. Such physical inventories can only occur once or twice per year in a large reprocessing plant.

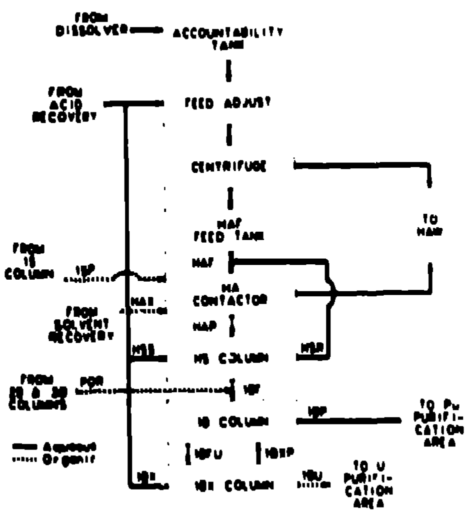

Fig. 1. Codecontamination-partition process block diagram.

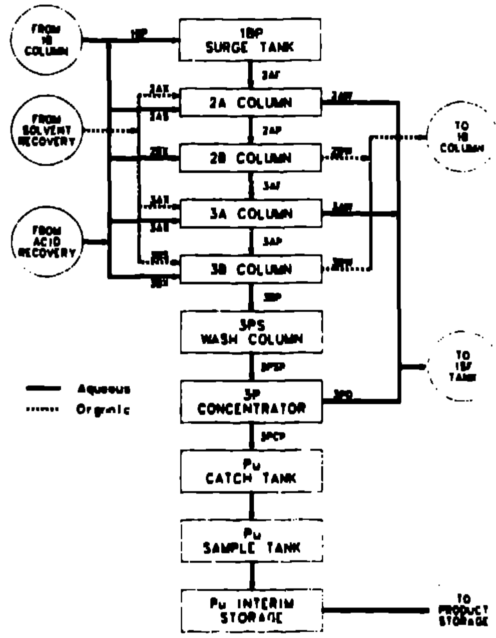

Fig. 2. Plutonium purification process block diagram.

Table I shows the additional information necessary for NRTA. Most of this information is already available from existing, or upgraded, process instrumentation. In a few instances, additional instruments are needed, especially for on-line measurements of concentrations in streams. These measurements are obtained by adding nondestructive measurements, such as x-ray flu rescence or x-ray absorption-edge densitometry, to appropriate sampler lines from the process.

C. Effectiveness of Materials Measurement and Accounting

Table II summarizes the effectiveness of NRTA in MBA 2, as determined for the reference process using computer-based modeling and simulation techniques. A range of uncertainty (one materials-balance standard deviation) is given for the chemical separations process over various accounting periods. The cases considered range from best-case estimates of pulsed-column in-process inventories (5%) with two-day recalibrations of feed and product flow and concentration measurements (to control correlated errors in the transfer measurements) to worst-case estimates of pulsed-column in-process inventories (20%) with no recalibrations of transfer measurements over the accounting periods. The diversion-detection sensitivity is usually quoted as a given number times the materials-balance standard deviation; for example, 3.3 σ could correspond to a 95% probability of detecting a significant diversion with a false-alarm probability of 5%. The results in Table II clearly indicate the improved sensitivity to short-term diversion provided by NRTA systems over conventional accounting systems.

TABLE I
MEASUREMENTS FOR NEAR-REAL-TIME ACCOUNTING IN THE
CHEMICAL SEPARATIONS PROCESS

Measurement Point	Material Description	Measurement Type	Instrument Precision (% 1σ)	Calibration Error (% 1σ)
HA feed tank	U, Pu, FP in HNO_3	Volume	3	--
	2.8 g Pu/L	Concentration	1	--
HS column	U, Pu, residual FP in organic and HNO_3, Pu inventory	See Footnote a	20	--
1B column	U, Pu in organic, Pu inventory	See Footnote a	20	--
1BP stream	U, Pu in organic	Flow rate	5	1
	<0.1 g Pu/L	Concentration	10	2
POR stream	U, Pu in organic	Flow rate	5	1
	0.01 g Pu/L	Concentration	10	2
1BP stream	U, Pu, residual FP in HNO_3			
	400 L/h	Flow rate	1	0.5
	5 g Pu/L	Concentration	1	0.3
1BP surge tank	U, Pu, residual FP in HNO_3	Volume	3	--
	5 g Pu/L	Concentration	1	--
2A column	U, Pu, residual FP in aqueous, organic phases; Pu inventory	Volume	5-20	--
		Concentration		
2AW stream	U, Pu, residual FP in HNO_3			
	500 L/h	Flow meter	5	1
	<0.1 g Pu/L	Concentration	10	2
2B column	U, Pu, trace FP in aqueous, organic phases, Pu inventory	Flow meter	5-20	--
		Concentration		
2BW stream	U, trace Pu in solvent			
	150 L/h	Flow rate	5	1
	Trace Pu	Concentration	10	2
3A column	U, Pu, trace FP in aqueous, organic phases, Pu inventory	Flow rate	5-20	--
		Concentration		
3AW stream	U, Pu, trace FP in HNO_3			
	215 L/h	Flow rate	5	1
	<0.1 g Pu/L	Concentration	10	2
3B column	U, Pu in aqueous, organic phases; Pu inventory	Flow rate	5-20	--
		Concentration		
3BW stream	U, trace Pu in solvent			
	105 L/h	Flow rate	5	1
	Trace Pu	Concentration	10	2
3PS diluent-wash	Pu in aqueous phase, trace Pu in organic phase; Pu inventory	Flow rate	5-20	--
		Concentration		
3P concentrator	Concentrated plutonium nitrate	Volume (constant)	--	--
	250 g Pu/L	Concentration	1.5	--
3PD stream	Residual Pu in HNO_3			
	32 L/h	Flow rate	5	1
	<0.1 g Pu/L	Concentration	10	2
3PCP stream	Plutonium-nitrate product			
	8 L/h	Flow rate	1	0.5
	250 g Pu/L	Concentration	1	0.3

[a]Inventories in the columns are estimated from process measurements of flows and concentrations in adjacent streams combined with engineering models.[12,13]

Decision analysis techniques were developed to analyze the large volume of data arising from NRTA systems.[14-20] The approach consists of using a battery of estimators, tests, and graphic displays to reduce the data, on-line, to a few easily recognizable descriptors. The analyst uses these descriptions to make decisions regarding the amount, location, and timing of suspected diversion.

III. EXTENSION OF NRTA SYSTEMS FOR INTERNATIONAL SAFEGUARDS

A. Inspector Verification

We have considered International Atomic Energy Agency (IAEA) inspector activities that are necessary to verify the operator's data for MBA 2.[2,3] The inspector's verification procedure is based on periodic examination of the

TABLE II

EFFECTIVENESS OF MATERIALS ACCOUNTING IN THE CHEMICAL SEPARATIONS AREA (MBA 2)

Accounting Period	Materials Balance Frequency	σ^a (kg Pu)
1 balance	1/2 days	2.1-2.4
1 wk	1/2 days	2.5-2.8
2 wk	1/2 days	3.0-3.6
1 month	1/2 days	4.0-5.7
3 months	1/3 months	7.5-14.0
6 months	1/6 months	15.0-26.8
1 yr	1/yr	23.8-52.7

[a] Materials-balance standard deviations for accounting periods <1 month are based on in-process inventory measurements while the process is operating. Materials-balance standard deviations for accounting periods >1 month assume a shutdown and cleanout physical inventory.

materials-balance data for each MBA. The inspector must verify that the operator's data are valid and complete, and that material unaccounted for (MUF) is sufficiently close to zero. Inspector verification activities include: (1) examination of safeguards-related information provided by the State in reports and maintained at the facility in records; (2) collection of independent information by the IAEA; and (3) comparisons of the information to establish the completeness, accuracy, and validity of the State's accounting data.

The IAEA verification of the operator's nuclear materials accounting system is based on examination of the materials balances with respect to diversion hidden by measurement uncertainties and diversion hidden by falsification of operator's data.

Diversion hidden by measurement uncertainties is possible because of the statistical uncertainty of the MUF calculation. It is important that measurement uncertainties be reduced to decrease the amount that could be diverted, but that the estimate of measurement uncertainties be realistic to maintain false-alarm rates at an acceptable level.

Concerns with diversion hidden by falsification of operator's data fall into three categories:

(1) understatement of inputs,
(2) overstatement of outputs, and
(3) overstatement of the current inventory.

Data falsifications are correlated from one MBA to the adjacent MBAs. Thus, an overstatement of outputs from one MBA will result in an overstatement of inputs to the next MBA. Detection of diversion in one MBA depends on adequacy of safeguards in adjacent MBAs, and correlation of verification activities among MBAs is important.

B. Key Measurement Points

The inspector must verify each key measurement point (KMP). He may participate in the operator's measurement control program and employ surveillance (both human and instrumental) of the operator's measurement procedures. The inspector examines the operator's and his own materials-accounting data to obtain an assurance that diversion has not occurred. Continuous IAEA inspector presence and on-site IAEA laboratory facilities are anticipated at large reprocessing plants.

A complete discussion of KMPs, strategic points, and inspector-verification activities is given in Ref. 2. A brief discussion is given here.

1. Input Measurements. The three input measurements to MBA 2 are the feed accountability tank, the plutonium product recycle tank, and the uranium rework tank. Understatement is a concern for the first two measurement points. Conventional materials accounting in MBAs 1 and 4 may be insufficient to meet this concern from the viewpoint of sensitivity and timeliness, therefore other safeguards measures may be required. (See Ref. 3 for a discussion of the role of containment and surveillance in the integrated safeguards system.) Understatement of inputs at the accountability tank can result from improper concentration measurements or through understatement of level and density measurements.

2. Output Measurements. Outputs in MBA 2 include recycle to MBA 1, product transfers to MBAs 3 and 4, and waste. The output measurements for which overstatement is of particular concern are the high-level liquid waste (HWW) sample tank and the plutonium product sample tank.

Overstatement might be accomplished by manipulating materials transfers, but in a different way than for understatement. Overstatement can result if material remains in a vessel to be measured a second time. Overstatement of waste measurements is a concern if the measurement limits cannot be set sufficiently close to zero. Then repeated overstatements of waste losses may result in a significant amount of material being available for diversion.

3. Inventory Measurements. Overstatement is a concern at the following inventory measurement points (see Figs. 1 and 2):

(1) feed adjust tanks,
(2) 1BP surge tank,
(3) HA feed tank,
(4) 3P concentrator,
(5) HS column,
(6) 1B column,
(7) 2A column,
(8) 2B column,
(9) 3A column,
(10) 3B column, and
(11) 3PS column.

Measurements at these points are used to estimate the in-process inventory for near-real-time materials accounting. Diversion of material at these points may be more difficult than at the flow KMPs because process constraints limit the amount of material that could be contained in these vessels and because removal of material could result in column or process upset.

C. Effectiveness of Inspector Verification

The inspector's problem of detecting falsified data and diversion hidden by measurement uncertainties can be addressed by applying the inspector's sufficient statistics.[3,21] The performance of these statistics in detecting abnormalities was evaluated for MBA 2 over a range of diverted amounts. The analyses assumed that the operator could falsify the data using an optimal data-falsification strategy, and that the inspector either has a measurement method with uncertainty comparable to the operator's method or can verify the operator's measurement and use it as his own.

Table III shows sensitivities of the inspector's sufficient statistic to a diversion of 8 kg of plutonium over various time periods. If the inspector uses only his own data in testing for missing material without regard to operator falsification, the sensitivity of the inspector's sufficient statistic to missing material meets the IAEA goal for detecting abrupt diversion (8 kg of plutonium in 7-10 days). If the inspector has not independently verified the operator's measurements, and wishes to use them in his analysis, then he must use a statistic to test for data falsification as well as diversion and accept a slightly reduced sensitivity.

The protracted diversion goal (8 kg in one year) cannot be achieved with 95% detection probability and 5% false-alarm probability by any conventional or near-real-time system based on current or projected technology. This diversion rate corresponds to ~0.05% of throughput for a 1500 tonne/yr plant. This value is unrealistically low for any current or contemplated safeguards system. However, a state-of-the-art conventional accounting system should be sensitive to the diversion of a few tenths of a percent (≤0.5%) of throughput over a 1-yr period. The NRTA component of a state-of-the-art accounting system will detect similar levels of diversion over shorter time periods. This means that the potential divertor's strategy against the combined accounting system is severely restricted, either to open seizure of nuclear materials and facilities or to extremely long-term, low-rate, repeated diversions involving complex and difficult-to-maintain concealment strategies.

TABLE III

SENSITIVITY OF INSPECTOR'S SUFFICIENT STATISTIC

MBA 2	Detection[a] Balance Period (days) 7	30	180	360
With No Falsification	0.97	0.82	0.25	0.20
With Optimal Falsification	0.94	0.75	0.20	0.17

[a]Diversion of 8 kg, 0.05 false-alarm probability.

TABLE IV

1980 MINIRUN DESCRIPTION

No.	Purpose	Special Test Activities
1	Shakedown	Program debugging; Column inventory experiment
2	Shakedown/baseline run	Accumulation of steady-state data
3	Announced diversions (all parties informed of diversion timing)	17 abrupt (batch) diversions ranging from 5 to 0.25 kg of uranium; 4 protracted removals, each of 16-h duration with rates from 0.2 to 0.6 kg/h of uranium
4	Unannounced diversions (accounting personnel not informed of timing)	3 abrupt removals of 0.3, 0.5, and 1.2 kg of uranium; 2 protracted removals of 0.5 kg/h of uranium, each ~12-h duration
5	DOE contractor demonstration	1 abrupt removal of 0.25 kg of uranium; 1 protracted removal of 0.85 kg/h of uranium for 16 h; Column inventory experment

IV. DEMONSTRATION OF NRTA AT AGNS

For acceptability of near-real-time accounting, the concepts described above must be demonstrated in a real plant environment. A first step toward this demonstration is being taken in a joint experimental program being conducted at the AGNS BNFP.[8-11]

A. Minirun Description

Five minirun experiments were performed at AGNS during 1980 with participation by Los Alamos National Laboratory to demonstrate NRTA and by Oak Ridge National Laboratory to demonstrate process monitoring.[22] Table IV summarizes the purpose and activities of each of the five runs.

Demonstration of NRTA at AGNS required that we develop an estimator for pulsed-column in-process inventories, formulate materials accounting strategies, and develop computer programs to acquire and analyze the measurement data. We developed these programs at Los Alamos and, with the support of AGNS personnel, implemented them on the AGNS computer system.[23]

The minirun cycle (Fig. 3) consists of four pulsed-column contactors (2A, 2B, 3A, and 3B); one packed column (3PS); a product evaporator (3P concentrator); and seven product, feed, and blending tanks. Support systems include aqueous waste tanks, a waste evaporator and acid fractionator, a solvent surge and recycle tank, an off-gas system, and associated process and chemical distribution systems. This represents a good cross section of routinely used plant equipment. Unirradiated natural uranium is used in place of plutonium for the tests.

The normal starting inventory for each run was 400-500 kg of uranium. After attaining equilibrium, a "process holdup" (pulsed columns, lines, product evaporator) of about 70-75 kg was observed, with the remaining material distributed among product tanks. Acid waste streams were collected in the acid recovery system throughout each run without recycle. These streams represent losses from the system that varied from run to run, averaging on the order of 100 kg for each run.

B. Measurements

Measurement data from the AGNS process-control instrumentation, including estimates of precision and correlated measurement uncertainties, were received in a data file (ARANGE) every hour. Sample data from the analytical laboratory were added to the ARANGE file as they became available.

The measurement data included volumes and concentrations for process tanks and flow rates and concentrations for process streams. The measurement types and locations are shown in Fig. 3. The level and density in each of the process tanks were measured using dip-tube manometers. The dip-tube manometers were calibrated automatically under computer control ~ once per shift by comparison with a high-precision digital manometer.[24] The uranium concentrations in tanks and organic product streams were calculated from on-line density, temperature, and free-acid measurements. Samples were taken periodically for chemical analysis from the 1BP surge tank, the column product streams, the waste streams, the solvent feed tank, and all feed and product batches. Flow rates of all organic and aqueous inlet streams were measured by process flowmeters. The 2AF flow rate was measured using a metering headpot.

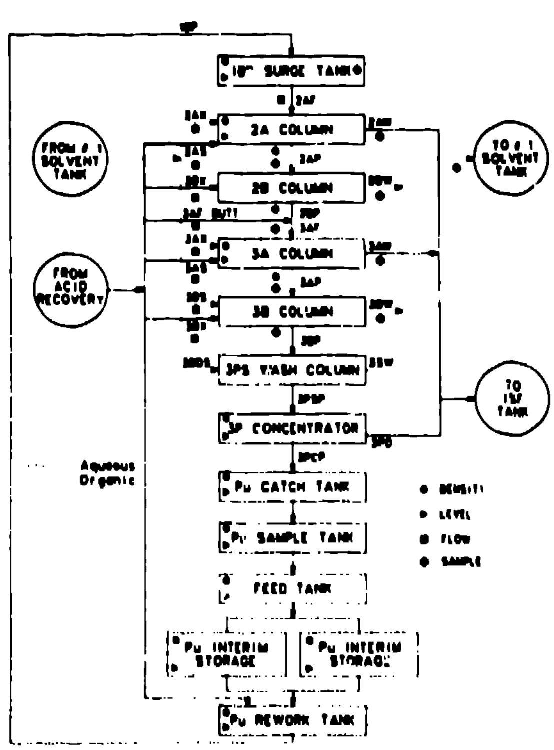

Fig. 3. AGNS minirun block diagram.

C. Analysis Programs

Three computer programs (RADAR, FUNNEL, and DECANAL) were developed at Los Alamos and transferred to AGNS for analyzing minirun measurement data. RADAR is a utility code that reads the measured data from ARANGE and performs minimal formatting and data checking. RADAR then writes the input measurement data file for the FUNNEL program. FUNNEL was written specifically for the AGNS minirun process. It is the executive program that forms materials balances. It also allows the user to select for analysis data spanning particular time periods and to select any of several UPAAs covering different areas of the process. FUNNEL calculates estimates of the pulsed-column in-process inventory, checks for uncovered dip tubes, flags unreasonable measured values, and tracks multiple batch transfers. It also builds tables of the raw measurement data, which are used to identify and explain anomalies such as plugged probes or other faulty measurements. For a specified UPAA and time period, the FUNNEL program combines the raw measured values to calculate net transfers, in-process inventories and their statistical uncertainties, and transmits them to the decision analysis (DECANAL) package for analysis.

The analysis methods are incorporated in the computer program DECANAL,[25] which calculates sufficient statistics containing all accounting information, sets decision thresholds, and compares these statistics to the thresholds in testing for losses.[14-20] The DECANAL output includes various graphical displays, such as alarm charts, that indicate the likelihood and location of diversion, and plots of various statistics that estimate the amount.

Data from each UPAA were examined by DECANAL using a two-step detection/assessment procedure. In the detection mode, materials-balance and CUSUM plots were produced for selected time intervals, along with tables and plots of measurement data from selected instruments. These data were scanned for evidence of probable outliers or trends. If significant losses of uranium were indicated, all the available data were investigated and alarm charts were generated. In the assessment mode, all subsequences of data from adjacent and overlapping UPAAs were tested at various levels of significance. The most significant sequence of materials-balances was identified, and the amount, time, and location of the apparent loss were determined from that sequence.

D. Pulsed-Column Inventory Estimation

Under normal process conditions it is not possible (or at least not very convenient) to measure the in-process inventory of nuclear material in the pulsed columns. However, estimates of the in-process inventory can be obtained, if flow-rate and concentration measurements are available on the column inlet and outlet streams.

The systems studies of near-real-time accounting[1,2] showed that estimates of the AGNS column inventories to 10% or better should be adequate for sensitive detection of losses. Under the sponsorship of Los Alamos, with participation by AGNS, General Atomic Company, Iowa State University, and Clemson University, techniques for estimating the inventory in the pulsed-column contactors were developed.[12,13]

Flow rates of all inlet streams are monitored to control the columns. For improved control and for NRTA, the concentrations of nuclear materials in the feed, product, and waste streams should also be measured. These measurements can be used to estimate the in-process inventory of nuclear materials in the columns. The form of the estimator is given by

$$H = H_f C_f + H_p C_p + H_w C_w \quad , \qquad (1)$$

where H is the total column inventory and C_f, C_p, and C_w are measured concentrations of nuclear material in feed, product, and waste streams; H_f, H_p, and H_w are constants determined experimentally and through engineering models for each pulsed column.

Experiments at AGNS during run numbers 1 and 5 indicate that the column inventory estimates are good to 5 to 25% for individual columns and to about 10% for the total uranium inventory in all four pulsed columns. These column inventory experiments consisted of draining the columns into holding tanks at the end of the minirun. The contents of the holding tanks were sampled and analyzed for uranium, and the measured uranium inventory was compared with the estimated inventory for each of the columns.

E. Accounting Strategies

The definition of several UPAAs with overlapping boundaries was desirable and possible because at certain points in the process there were redundant measurements. For example, the 1BP tank drop-out rate and the 2AF stream headpot flow meter both measure the 2AF stream flow rate. Likewise, product solutions can be measured in the product catch tank, the product sample tank, and the product storage tanks. Materials-balance data from overlapping UPAAs and redundant measurements were useful in detecting and localizing losses and in maintaining continuity when there were measurement problems.

The five UPAAs most often analysed are:

1. Full Process UPAA - includes the entire closed loop of the plutonium purification process, as operated for the miniruns;
2. Column UPAA - isolates the columns into a single accounting area bounded by the 1BP tank and the 3P concentrator;
3. 1BP surge tank UPAA - isolates the 1BP surge tank bounded by the plutonium rework tank and the 2AF stream;
4. PPP UPAA - includes the columns and the 3PS concentrator with boundaries at the 1BP surge tank and the Pu catch tank (alternatively, the catch tank can be included in the UPAA, and the sample tank can be used for the output transfer measurement); and
5. Tank UPAA - isolates any single tank in the process as a separate UPAA.

F. Results

Sample NRTA results obtained during miniruns 3, 4, and 5 are shown in Figs. 4-7. Data analysis using the materials-balance and the CUSUM statistics are included in the examples. Each figure shows plots of the test statistic and the corresponding alarm chart. Each test statistic is plotted sequentially in time with 1σ error bars. The alarm chart is a point plot of initial time vs final time for each sequence of materials balance data that caused an alarm. The position of each point on the chart indicates the time period over which each alarm occurred. The significance of each alarm is indicated by the plotting symbol. The letters A-G are used to indicate increasing level of significance. Thus, the chart indicates the relative importance of alarms and helps to localize them in time.

Figure 4 is a materials-balance and alarm chart for a static storage tank during minirun 3 over a period when a series of abrupt diversion tests (5.2, 2.6, 1.3, 0.65, and 0.26 kg of uranium) was conducted. The first and second diversions caused significant alarms, whereas the other three removals did not generate any alarms because they were not statistically significant. The estimated amount of material in the first two diversions is 6.0 and 3.1 kg, respectively. The difference between the estimated loss and the true loss results from differences between the chemical analysis of the diverted material and the on-line concentration measurements for the storage tank.

Figure 5 shows materials-balance, CUSUM, and CUSUM alarm charts for another (nonstatic) diversion during minirun 3 from a storage tank. The CUSUM alarm chart shows numerous, highly significant alarms representing long sequences of materials balance data. This indicates that a protracted diversion test occurred between 1700 on 7/17/80 and 0900 on 7/18/80, resulting in the removal of 4.1 kg of uranium. AGNS records later showed that 3.6 kg of uranium was removed between 1750 on 7/17/80 and 1055 on 7/18/80.

Figure 6 shows materials-balance, CUSUM, and CUSUM alarm charts for the column UPAA during a 100-hour time period of minirun 4. The only prominent feature in the materials-balance chart

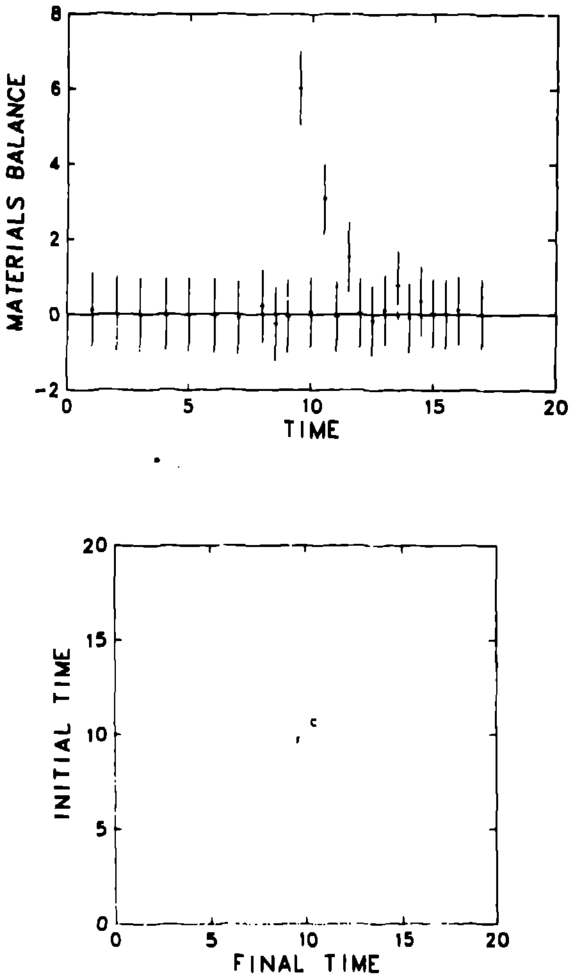

Fig. 4. Tank 305 (0000 7/17/80 – 1700 7/17/80: materials balance chart (upper), materials balance alarm chart (lower).

consists of three balances ~50 hours into the run. These balances result from a clerical error in reporting a uranium product-concentration analysis. Three separate positive trends are apparent in the CUSUM, corresponding to two protracted diversion tests from intermediate column product streams (20 to 40 hours from 2BP and 80 to 100 hours from 3BP) and a rapid loss of uranium to acid waste (50 to 70 hours). The alarm chart shows three clusters of alarms corresponding to these diversion tests. All three trends produced highly significant alarms.

Figure 7 shows a CUSUM and its corresponding alarm chart for the column UPAA (AF stream to 3BP stream) during minirun 5. During this time period, some problems were experienced with the 2AF flowmeter; yet we were able to draw materials balances about this UPAA by using the 1BP tank dropout rate instead of the flowmeter to determine the input transfer to the UPAA. This illustrates the importance of including

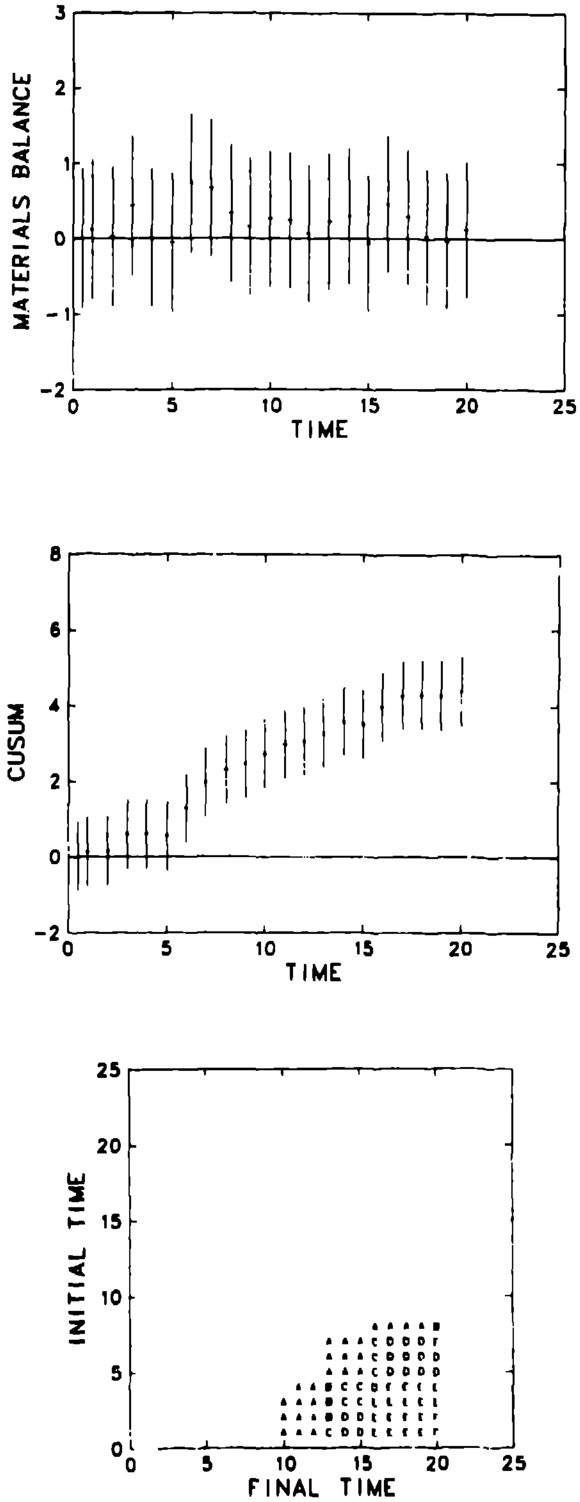

Fig. 5. Tank 305 (1500 7/17/80 – 1700 7/18/80): materials balance chart (upper), CUSUM chart (middle), and CUSUM alarm chart (lower).

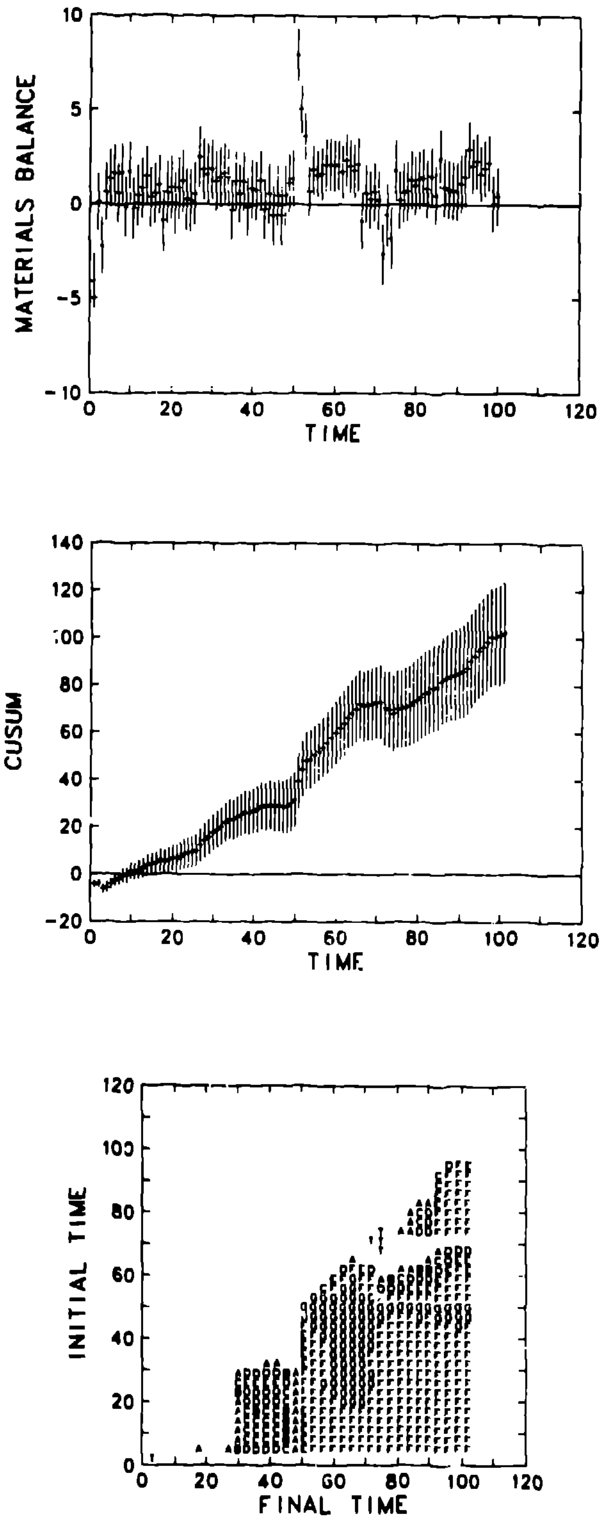

Fig. 6. Column UPAA (0700 9/4/80 - 1200 9/8/80): materials balance chart (upper), CUSUM chart (middle), and CUSUM alarm chart (lower).

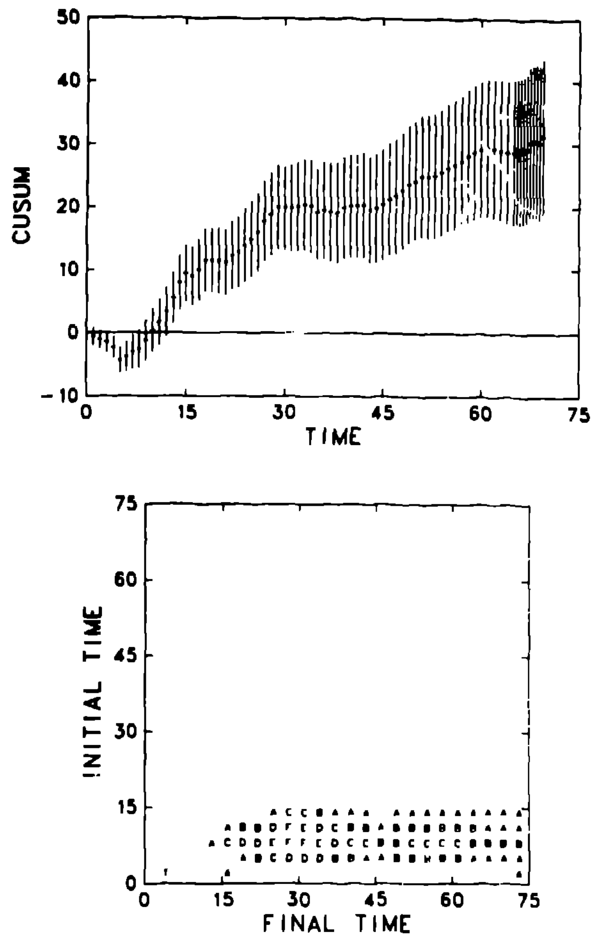

Fig. 7. Column UPAA (2000 11/18/80 - 1650 11/21/80): cusum chart (upper) and cusum alarm chart (lower).

overlapping UPAA boundaries and redundant measurements in the design of NRTA systems. The CUSUM shows a significant trend, and the corresponding alarm chart indicates that the most significant sequence started at 5 hours (0000 11/19/80) and ended at 29 hours (0400 11/20/80). During that time we estimated that 24 kg of material was diverted. AGNS records later indicated that 21 kg of material was removed from the 1BP tank during the period 0000 on 11/19/81 through 0115 on 11/20/81.

V. CONCLUSIONS AND FUTURE WORK

A. Conclusions

Substantial progress has been made in developing and demonstrating near-real-time systems for reprocessing plants. The results of the AGNS miniruns show that the technique of near-real-time accounting for nuclear materials can detect losses from the process area of a large nuclear fuels reprocessing plant. The minirun experiments also show that the functions and in-plant systems of NRTA and process control are compatible and mutually supportive.

Measurements of flow rates and concentrations are needed on process streams, including waste streams, that cross accounting area boundaries. Some of these measurements can be obtained from process flowmeters and instrumentation on adjacent process vessels. A few measurements at flow key measurement points require the placement of nondestructive instrumentation on available sample lines.

In-process inventory measurements and estimates for process tanks and vessels usually can be obtained from available process control data. These measurements in general need not be as accurate or precise and may be made less often than the flow measurements. Estimates that are satisfactory for NRTA by combining flow and concentration measurements on inlet and outlet streams with pulsed-column models can be made of the in-process inventory in pulsed columns.

Overlapping UPAAs and redundant measurements are helpful for system reliability and for localization and detection of losses.

Computerized analysis and display methods geared to ease of understanding and interpreting the data and the status of the process are necessary components of near-real-time systems.

B. Future Work

The reprocessing facility is an integrated whole, and the safeguards system must address the entire facility. Further in-plant testing of NRTA is required throughout the entire process to refine the technique, particularly the use of data from on-line instrumentation. Process monitoring data generally are sensitive to small changes in process tanks and columns and should be better integrated into the overall system. The final integrated system must be tested in a "hot" facility.

The credibility of these systems for international safeguards must be demonstrated through tests jointly with the IAEA. These tests are necessary to develop specific inspector-verification methods for near-real-time systems and to evaluate the overall sensitivity to diversion.

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